Visual Discomfort Induced by Relative Disparity and Planar Motion of Stereoscopic Images

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Jing Li, Marcus Barkowsky, Patrick Le Callet
LUNAM Université, Université de Nantes, IRCCyN UMR CNRS 6597
(Institut de Recherche en Communications et Cybernétique de Nantes)
Polytech Nantes, rue Christian Pauc BP 50609 44306 Nantes Cedex 3, France
{jing.li,marcus.barkowsky,patrick.lecallet}@univ-nantes.fr

***Abstract*—Viewers often complain of visual discomfort or visual fatigue after viewing the stereoscopic images. In this paper, we investigated the effects of planar motion at different depth levels on visual discomfort. In the subjective experiments, the Paired Comparison method was used to allow for a precise measurement. The Bradley-Terry model was used to analyze the subjective experimental data. The experimental results indicated that the relative angular disparity between foreground object and background played a more important role in determining the visual discomfort than the vergence-accommodation conflict. Furthermore, viewers might experience more visual discomfort with the increase of planar motion velocity. In a practical application of our study, it may be concluded that for stereoscopic motion images, the depth range for fast motion sequences should be significantly reduced and for slow motion sequences, the depth range may be increased.**

I. INTRODUCTION

Stereoscopic images have drawn more and more attention recently as they can give viewers a totally different and enhanced viewing experience. The three-dimensional (3-D) technology can be applied on numerous areas, e.g. television broadcast system, video games, telecommunications, telemedicine, education. Nevertheless, viewers often experience visual discomfort during the 3-D viewing process which may mangle the viewer's enthusiasm. It seems to be one of the critical factors that impede the development of 3-D on some applications. A number of researches about visual discomfort and visual fatigue have been conducted recently. One of the widely accepted main reasons that may cause visual discomfort is the vergence-accommodation conflict[1]. Some researches show that the distortions in 3D video such as Crosstalk may induce visual discomfort[2]. Besides, the visual discomfort may occur when the stereoscopic images involve a motion component in depth even if they are displayed within the range of depth of field[3].In our previous study[4], we also found that the relative disparity between the background and foreground played an important role in determining visual discomfort, and the planar motion velocity also influenced the visual discomfort. However, this study was based on the experts-only (viewers are experts in 3-D related research area) subjective experiment results with only 10 observers, which may not give a comprehensive conclusion for the non-expert observers. In this study, we conducted a similar subjective experiment to our previous study but with non-expert observers to verify our previous findings.The Bradley-Terry model[5] was applied on the subjective paired comparison experimental data, which can provide a tractable estimators for scales, simultaneous confidence intervals and significant differences between two stimuli.

II. EXPERIMENT

A. Experimental design

The main task in this study is to investigate the effects of disparity and planar motion velocity on visual discomfort. Thus, five binocular disparity levels and three velocity levels are selected. Three of the binocular disparity levels were within the comfortable viewing zone[6], two were outside it. The five angular disparity levels were $0,\pm0.65,\pm1.3$ degree assuming the interpupillary distance was 65 mm and the viewing distance was 90 cm. Three velocity levels which represent slow, medium and fast were chosen and will be explained in next session.

B. Stimuli

Computer-generated stereoscopic sequences were used in this study to avoid the influence of other factors on visual discomfort. The stereoscopic sequences consisted of a left-view and a right-view image which were generated by MATLAB psychtoolbox[7]. Each image contained a foreground and a background. A 480×480 pixels black maltese cross was the foreground object, and it moved along a trajectory which was a circle with center point at the center of the screen, and a radius of 300 pixels. The motion direction was anti-clockwise. As the trajectory was a circle, the velocity was expressed in degree/s. The three velocity levels were 71.8, 179.5 and 287.2 degree/s, which represented slow, medium and fast, respectively. The background was placed at a fixed position whose angular disparity is -1.4 degree. It was generated by adding salt&pepper noise on a black image,and then filtered by a circular averaging filter. A black circle which was the same as the moving track of the object was placed on the background to give the viewers a reference of the trajectory.

C. Apparatus

The stereoscopic sequences were displayed on a Dell Alienware AW2310 23-inch 3-D LCD screen (1920×1080 full HD resolution, 120Hz), which featured 0.265-mm dot pitch.

The display was adjusted for a peak luminance of $50 cd/m^2$ when viewed with the active shutter glasses. The graphics card of the PC was an NVIDIA Quadro FX 3800. Stimuli were viewed binocularly through the NVIDIA active shutter glasses (NVIDIA 3D vision kit) at a distance of about 90 cm, which was approximately three times of the picture height. The peripheral environment luminance was adjusted to about $44 cd/m^2$. When seen through the eye-glasses, this value corresponded to about 7.5 $cm/m^2$and thus to 15% of the screen's peak brightness as specified by ITU-R BT.500.

D. Viewers

Forty-five viewers participated in this subjective experiment. Twenty-one are male, twenty-four are female. They are all non-expert in this field. Their ages ranged from 18 to 44 years old with average age 24. All have either normal or corrected-to-normal visual acuity.

E. Procedure

In the experiment, the viewers watched a pair of stimuli at one trial, and then they were asked to select the one which made them feel more uncomfortable. A total of 105 pairs were presented in each individual subjective experiment.The subjective experiment contained a training session and a test session. All explanations were given in training session to make sure the viewers knew about the process and task of this experiment clearly.

III. Experimental results

As there were a foreground object and a background in the stimulus, the relative disparity between the foreground object and the background was used to analyze their effects on visual discomfort. The binocular angular disparity of the background was -1.4 degree, thus the 5 relative angular disparity levels of the foreground object were 0.1, 0.75, 1.4, 2.05, 2.7 degree. The Bradley-Terry scores for visual discomfort from experts and non-experts data are shown in Fig.1. It indicates that the visual discomfort increases with the relative angular disparity rather than the absolute angular disparity of the object. The influence of the vergence-accommodation conflict seems to be quite small under this experimental setup. It might be explained by the existence of the background and the moving foreground. There would be two vergence points in the stimulus for the viewers. When watching the stimulus, the viewers' attention may switch between the two objects. The larger of the depth distances between the visual attention points, the larger the abrupt change of the amount of vergence-accommodation mismatch when switch from one object to another, which might be seen as a reason that induces the visual discomfort. It was also clearly indicated that the perceived visual discomfort increases with velocity. This conclusion is in accordance with our previous study.

IV. Conclusion

In this study, the experimental results provided some new findings. The relative angular disparity between the foreground and the background might be more significant in determining the visual discomfort than the binocular angular disparity of the foreground. The vergence-accommodation conflict might not significantly affect the visual discomfort in this study. And, the planar motion with faster velocity results in more visual discomfort. In a practical application of our study, it may be concluded that for fast motion sequences, the depth range of the sequences should be significantly reduced and for slow motion sequences, it may be increased.

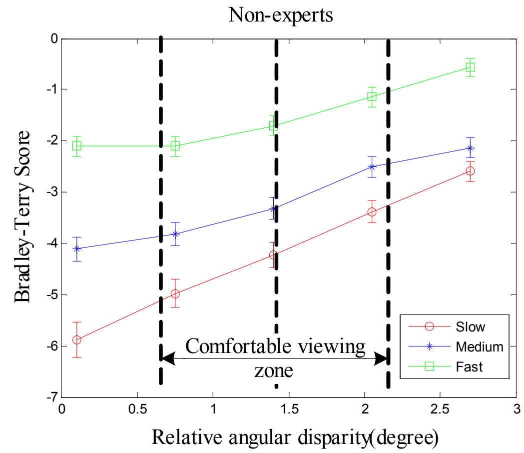

Fig. 1. Bradley-Terry scores for visual discomfort. The different lines represent different velocity levels, where slow, medium and fast represent 71.8, 179.5 and 287.2 degree/s. The outer two dashed lines represent the upper and lower limits of the comfortable viewing zone, which are 0.66 and 2.14 degree. The dashed line in the middle represents the position of screen plane. The error bars are the 95% confidence interval.

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